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RESEARCH PAPER

Landscape transformation analysis employing compound interest formula in the Nun Nadi Watershed, India

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Abstract The Nun Nadi watershed is close to the Dehradun city and some settlements are spread over the Mussoorie hills. Landsat TM images of the year 2000 and 2009 were used to analyze the changes in Land Use/Land Cover (LULC) data employing compound interest formula. The main reason to choose the time period is that Dehradun was declared capital of Uttrakhand state of India in the year 2001. We observed rapid changes in the LULC data in the time period studied. This is primarily due to urban growth that increased exponentially after 2001 near Dehradun city and Mussoorie hills. The highest positive change rate was observed in the built-up and agricultural land which increased 8.39 and 9.92 percent, respectively. Interestingly we noticed that the dense and sparse vegetation shrunk in terms of land coverage, on the other hand, drastic negative change was observed in the bare/barren soil class. Taken together, these results indicate significant changes in various land use categories.

1. Introduction

Increasing human pressure on land disturbs the whole environment. Urbanization, desertification, and agriculture are some human driven land use change examples that significantly altered the surface of the earth and in this sense land use is an important element of global change (Vitousek, 1992; IPCC, 2000). The global, regional and local scale studies are obtaining a great deal of attention for the characterization of the carbon cycle (Melillo et al., 1993; Myneni et al., 1997). An understanding of land use/land cover change at different scales is important

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in an increasingly human-dominated biosphere. The correct identification and interpretation in land cover and/or land use change is of great interest in environmental change studies (Dale, 1997; Lambin et al., 2001; Vitousek et al., 1997).

It has been identified that land-cover change has the most pervasive human impact on natural systems (Vitousek, 1994) and urbanization is perhaps the most severe agent which is highly responsible for land cover change because of its dissimilarity to native habitats and its permanence (Marzluff and Ewing, 2001). 14% of the world's population was residing in urban areas only by 1900 and this figure had increased to 47% by 2000 (Brockerhoff, 2000). At the end of 2030, the percentage would be 60% of the urban population.

The human modification on the earth's terrestrial surface is responsible for the change in land use. Even though, natural processes may also contribute to changes in land cover, the major driving force is human induced land uses (Allen and Barnes, 1985). Although humans have been modifying land to obtain food and other essentials for thousands of years, yet current rates, extents and intensities of land use /land cover change are far greater than ever in human history, leading to unprecedented changes in ecosystems and environmental processes at local, regional and global scales. Today, land use / land cover changes encompass the greatest environmental concerns of the human population including climate change, biodiversity depletion and pollution of water, soil and air.

The history of urban growth indicates that urban areas are the most dynamic places on the earth's surface. Despite their regional economic importance, urban growth has a considerable impact on the surrounding ecosystem (Yuan et al., 2005). Most often the trend of urban growth is toward the urban–rural-fringe where there are less built-up areas, irrigation and other water management systems. In the last few decades, a tremendous urban growth has occurred in the world, and demographic growth is one of the major factors responsible for the changes. This urban growth is a common phenomenon in almost all countries over the world though the rate of growth varies. Currently, these are the major environmental concerns that have to be analyzed and monitored carefully for effective land use management.

The updating and obtainment of information about the current condition and the continuous dynamic changes of our earth's surface in remote high-mountain regions is a task where remote sensing technologies can best display their advantages. Land use cover (LUC) assessment is one of the most important parameters to meaningfully plan for land resource management. LUC inventories are assuming increasing importance in various resource sectors like agricultural planning, settlements surveys, environmental studies and operational planning based on agro-climatic zones. The knowledge of spatial land cover information is essential for proper management, planning and monitoring of natural resources (Zhu, 1997). The multi-temporal data are frequently used to generate landscape-based metrics and to assess landscape condition and monitor status and trends over a specified time interval (Jones et al., 1997).

Remote Sensing (RS) and Geographic Information System (GIS) tools have been used for collecting significant amounts of data from the earth's surface. RS provides an excellent source that helps in updating land use/land cover (LULC) information and through that, changes can be extracted, analyzed and simulated efficiently. RS in the form of aerial photography provides widespread information of urban changes (Bauer et al., 2003). It should also be noted that LULC mapping using remote sensing has long been a research focus of various investigators (Civco et al., 2002). Thus, currently, monitoring and mediating the adverse consequences of land use/land cover change while sustaining the production of essential resources has become a priority of researchers and policy makers around the world (Erle aand Pontius, 2007).

2. Study area

Nun Nadi Watershed (NNWS) is located in the North Eastern part of the Doon Valley between 30°20′08″ to 30°28′18″ N lat-

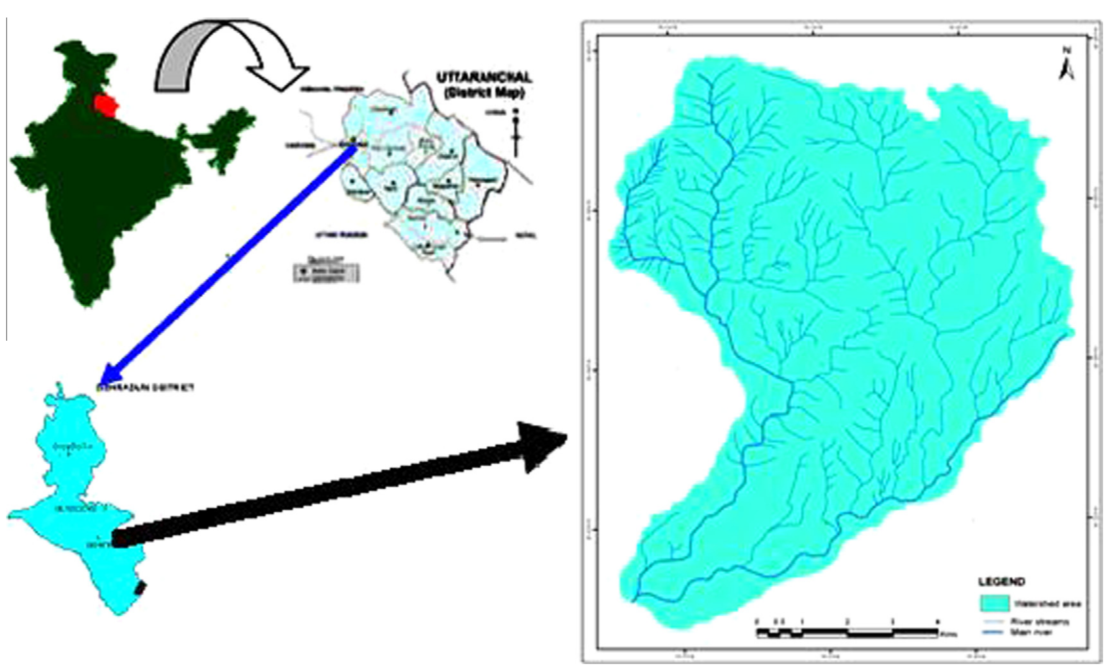

Figure 1 Geographical location of the Nun Nadi Watershed.

itudes and 77°58′36″ to 78°06′21″ E longitudes and encompassing an area of nearly 8697.33 hectares in the Yamuna river catchment in the Uttrakhand state of India (Fig. 1). The Dehradun city falls under the watershed and the study area is mainly situated between Dehradun and Mussoorie by south and north respectively. Land use changes have been observed by various researchers near Dehradun and they found a rapid increase in built-up area or urban growth after (2000) the declaration of Dehradun as the capital of the Uttrakhand state.

It is a part of the Shiwalik Himalayas with varying elevations ranging between 600 and 2000 m. The average annual rainfall of the Dehradun station is 2073.3 mm and about 87% of the annual rainfall in the area received during the months of June to September, July and August being the rainiest months. The average temperature of the study area is 20 °C approximately. The variation in the rainfall from year to year in the area is appreciable. The area has sub tropical climate with cold winters, warm and crisp springs, hot summers and a strong monsoon and surrounded by the Himalayas in the North.

3. Objectives

The broad objectives of the study are:

(i) To prepare a LULC layer for the year 2000 and 2009.
(ii) To assess the pattern, magnitude and direction of LULC change.
(iii) To calculate the pixel based change matrices to analysis the land transformation from one class to another.
(iv) To identify the causes of LULC changes in the Nun Nadi Watershed.

4. Materials and methods

Landsat TM (path 146, row 39) data of the year 2000 and 2009 were downloaded from USGS Earth Resources Observation Systems data center. All visible and infrared bands (except the thermal infrared) were included in the analysis. ENVI 4.7, ERDAS Imagine 9.2, Arc Map 9.2 and Ms. Excel 2007 were used for image processing, mapping and analysis, respectively. Simple differencing has been used for more accurate change detection techniques (Woodwell et al., 1983; Singh, 1989). Classification method of two Landsat images, 2000 and 2009 is carried out by using Maximum Likelihood Classifier (MLC) in ENVI 4.3. A supervised classification has been used through Maximum Likelihood algorithm (Wu and Shao, 2002; McIver and Friedl, 2002) and the compound interest formula has been utilized for change rate calculation (Puyravaud, 2003). The methodology is presented in the form of schematic flow chart in Fig. 2.

Several methods have been developed to detect the changes in LULC (Lambin and Ehrlich, 1997; Mas, 1999), but by far the most popular has been the utilization of post classification comparison method. In spite of the numerous evaluations of these techniques (Weismiller et al., 1977; Stow, 1990), no standard techniques have yet been adopted (Macleod and Congation, 1998) for all cases.

The change rate of LULC gives the rate at which a land class changes to another land class within a given time span. Change rate gives the magnitude and direction of changes.

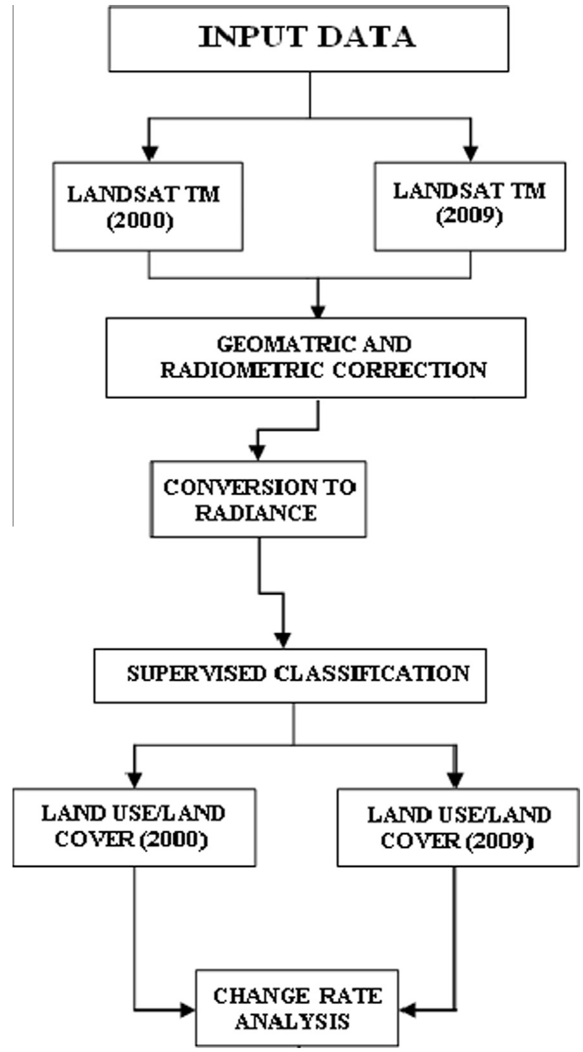

Figure 2 Schematic flow-chart of the methodology for LULC change analysis.

There are different formulae for calculating the change rate but here the formula developed by Puyravaud (2003) is used for calculation of change rate which has been derived from the compound interest formula:

$$r = \frac{[\ln(A_{t1}) - \ln(A_{t2})]}{t_1 - t_2} \times 100$$

where, r is the rate of land cover change, ln is log and A_{t1} and A_{t2} are the land cover (area of one class) at time t_1 and t_2 respectively.

Change detection techniques help in quantifying the temporal and spatial aspects of change. Change matrix represents the area that has undergone transition. The diagonal cells of the matrix represent the area that has remained under the same class in both the time periods, whereas the non-diagonal elements represent transitions from one class to another (Table 1).

Pre and post field surveys have been done and pictures have been captured during the field visit. Survey through DGPS and pictures (taken in field) have been used at the time of confusion when selecting the signature for supervised classification and also utilized to check the accuracy of LULC classification work.

Table 1 Change matrix for 2000 and 2009.

2000	2009							
	*	DV	SV	BU	WB	SL	AGL	FL	BS/BL
	DV	1475.25	591.48	87.3	6.66	15.84	14.85	10.8	18.99
	SV	319.14	1952.24	299.34	29.97	247.77	265.41	76.59	42.3
	BU	16.65	44.91	380.58	8.91	10.8	49.32	20.88	12.06
	WB	0.99	0.9	6.3	394.65	1.17	1.08	3.6	2.16
	SL	4.68	175.05	14.13	2.97	169.32	63.18	8.55	15.3
	AGL	9.54	34.11	30.51	11.97	63.63	99.94	31.68	3.78
	FL	35.19	93.06	204.84	21.87	24.03	105.93	189.28	11.43
	BS/BL	41.76	249.93	134.82	17.91	38.34	96.84	50.94	233.93

* DV, dense vegetation; SV, sparse vegetation; BU, built up area; WB, water bodies; SL, scrub land; AGL, agricultural land; FL, fallow land; BS/BL, bare soil/barren land.

Table 2 LULC status in Nun Nadi Watershed- 2000 and 2009.

Land use land cover classes	Area in hectares (2000)	Area in percent	Area in hectares (2009)	Area in percent
Dense vegetation	2220.21	25.53	1902.72	21.88
Sparse vegetation	3233.34	37.18	3145.83	36.17
Built-up area	538.83	6.20	1158.84	13.32
Water bodies	411.48	4.73	495.36	5.70
Scrub land	450.72	5.18	567.9	6.53
Agricultural land	285.75	3.29	695.97	8.00
Fallow land	689.13	7.92	391.77	4.50
Bare soil/barren land	867.87	9.98	338.94	3.90
Total	8697.33	100.00	8697.33	100

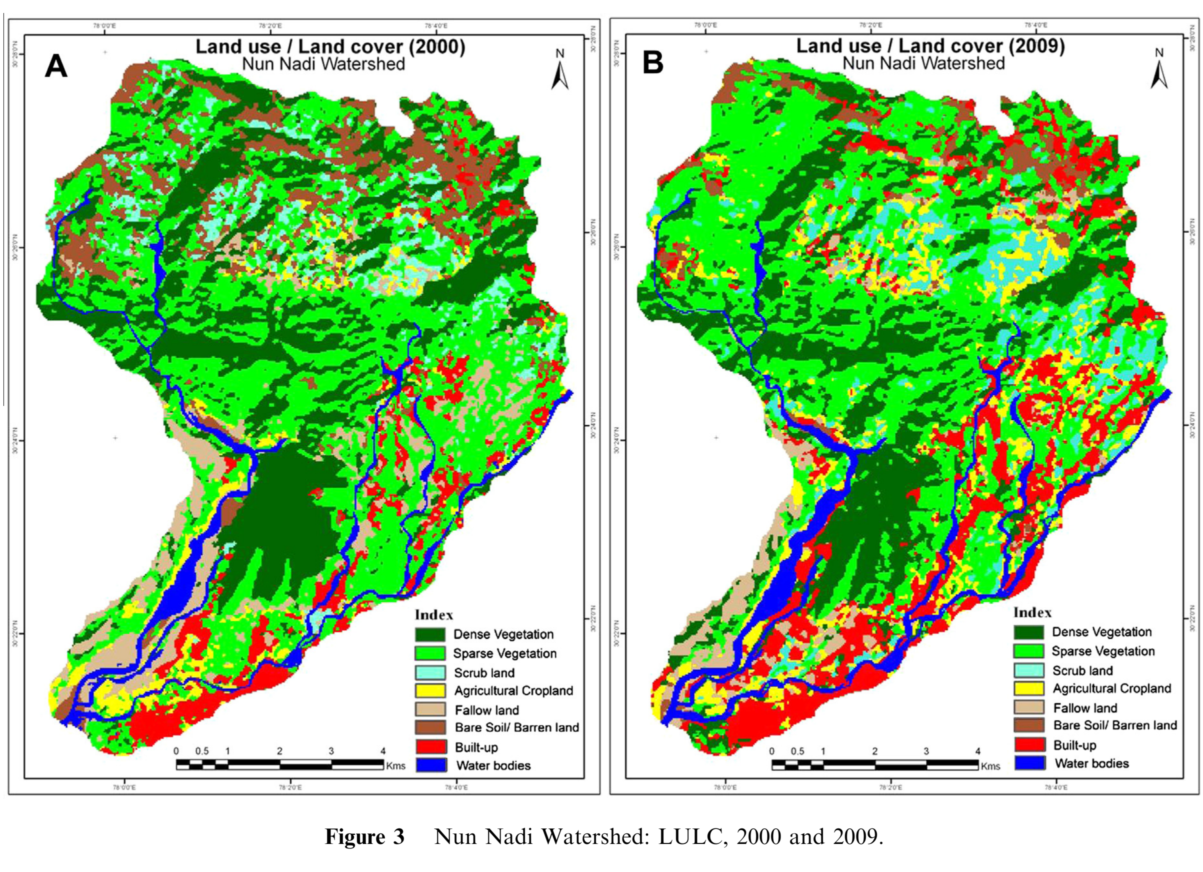

Figure 3 Nun Nadi Watershed: LULC, 2000 and 2009.

5. Results and discussion

5.1. Land use/land cover status 2000

Table 2 and Fig. 3(A) show the distribution and proportion of different land use classes in 2000. The area under study is largely hilly and covered with dense to sparse evergreen forest predominantly *sal*. Vegetation occupies about 63% area. The highest concentration of dense vegetation is found in the lower part of the watershed. There is an inverse relation between settlement and elevation i.e. as the elevation increases the concentration of settlements decreases. It is found that almost all the major settlements are confined to the lower portion of the watershed whereas few instances are recorded in the north-eastern part. The western part where the topography is highly undulating and forest concentration is high, is devoid of settlements. As such the settlements occupy about 6.20% area. The study area is drained by numerous rills and streams, both seasonal and perennial and discharges their water into the Nun Nadi. These rills and streams together occupy about 4.73% area. Undulating topography and a large forest cover have left little space for the development of sedentary agriculture. As such the area under agriculture is merely 3.29%. Following is a standard practice of undeveloped agriculture. On satellite images, these are identified generally on the basis of reflectance and location. The fallow lands appear as white patches in between the crop lands. Since agriculture in this region is undeveloped, therefore, a large part of agricultural land is left uncultivated to regain the fertility in a natural way. In such cases the area under fallow will always be greater than the cropped area. As a result the area under fallow is 7.92% (Table 2). The scrub and barren lands, together account for about 15% geographical area of the Nun Nadi Watershed.

5.2. Land use land cover status 2009

Fig. 3(B) and Table 2 show the status of LULC in 2009. It is evident that the sparse and dense vegetation classes are still dominant with a declining rate among all as they account for about 58% of the geographical area. The decline in the forest cover may be attributed to a sharp increase in the built-up area after the birth of State of Uttrakhand and Dehradun as the capital in 2001. Most of the built up land increase is observed on the Mussoorie hills. The built-up area has almost doubled to 13.32% (Table 2). After the declaration of the state, the state government made a sincere effort in conserving the natural resources particularly the forest cover and the water bodies. The government with the local support minimized the reckless cutting of forest and almost stopped illegal mining of the river bed. It has resulted in a moderate decline in forest area and an increase in the area under water bodies from 4.73% to 5.70%. The increase in built-up area particularly settlement has resulted in a sharp increase in the cropland area. Currently it occupies about 8% area. During the last ten years the agriculture in this region has improved significantly moving from primitive subsistence to intensive subsistence. This subsequently leads to a decline in the area under fallow land. Currently only 4.50% area is categorized under fallow land. Generally, the increase in area under settlement and agriculture is at the cost of forest and barren lands. As a result the area under barren land has declined from 9.98% to 3.9%.

5.3. Change analysis of LULC

Several things have been noticed to find out the changes in LULC using different approaches to clarify the statements of results.

Spatial pattern of landscapes plays an important role in determining the health of ecosystems. However, LULC change also affects these spatial patterns of landscapes. These change processes (landscape transformation types) experienced by LULC classes may vary. The results show that the dense forests are getting dissected, i.e. the area under the class is decreasing but the patches increase. Open forest and settlement areas are undergoing creation indicating that both the area and number of patches of a class increase. Attrition refers to a decrease in both area and number of patches in a class while, aggregation refers to decrease in the number of patches while increasing or a constant area under a class.

The bars in the positive area represent positive relation between the contributor class and host class, i.e. the contributor class has contributed to an increase in the host class. Similarly the bars in the negative area represent negative relation between the contributor class and host class, i.e. the contributor class has contributed to a decrease in the host class. The graphs indicate that the main contributors to the change in dense vegetation area are increasing scrub land, barren land, some agricultural land over hilly areas in terms of terrace farming and built up area (though the contribution is very

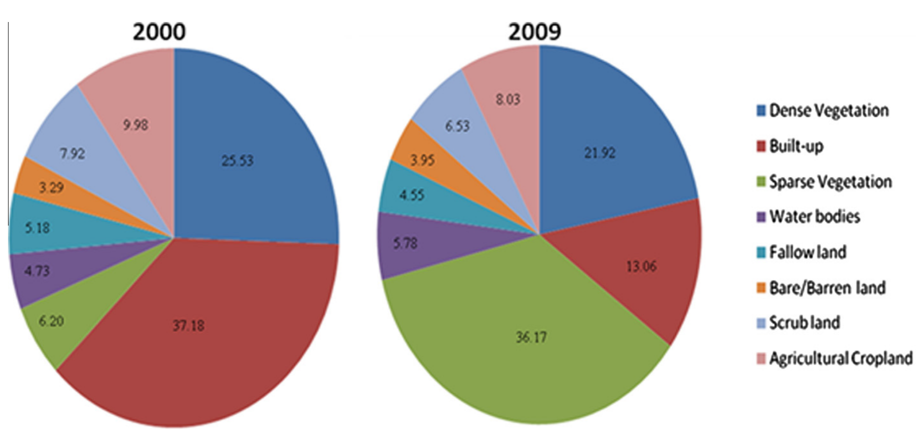

Figure 4 Percent share of land use categories, 2000 and 2009.

Table 3 Landscape transformation rate and type from 2000 to 2009.

S. No.	Land use land cover classes	Change rate in percent	Type
1	Dense vegetation	−1.72	Dissection
2	Sparse vegetation	−0.32	Dissection
3	Built-up area	8.39	Creation
4	Water bodies	2.07	Creation
5	Scrub land	2.57	Creation
6	Agricultural cropland	9.92	Creation
7	Fallow land	−6.20	Attrition
8	Bare soil/barren land	−10.37	Attrition

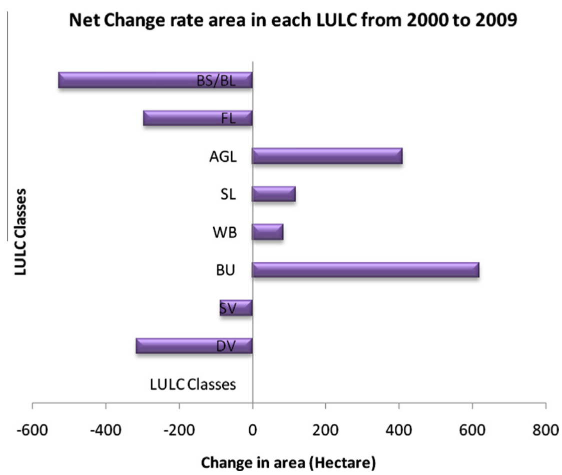

Figure 5 Overall net change in LULC classes- 2000 to 2009.

less). The forested areas do not contribute significantly in the increase in built up areas.

Information from change matrix was used to calculate the change rate in LULC classes. From the calculated change rate, it can be seen that the rate of deforestation of dense vegetation has increased over time, whereas area under sparse vegetation is increasing due to the conversion of dense forests into sparse vegetation. According to Fig. 4(a), scrub land also shows a positive growth rate from 2000 to 2009 due to the degradation of forested areas.

It is found that highest positive changes are recorded in agricultural land (9.92) and built-up (8.39) category followed by water bodies and scrub land (<2.50). Dense vegetation and sparse vegetation reported an insignificant decline in area (about −2%) whereas, fallow land (−6.20%) and barren land (-10.37%) recorded very high negative changes in percent during the study period (Fig. 4(b) and Table 3).

5.4. Main contributors of change in different LULC classes

Fig. 5 indicates that bare soil/barren land, fallow land, dense and sparse vegetation has decreased, whereas, agricultural land, built up area, water bodies and scrub land have increased. Increase in built up area between 2000 and 2009 can be due to a rapid increase in population after the declaration of Dehradun as the capital of Uttrakhand.

5.4.1. Dense vegetation

Fig. 6 signifies that the main contributors to the change in dense vegetation are increasing scrub land, barren land, and some agricultural land in the higher reaches of the study area. The main contributors to increase in built up area are fallow land, sparse vegetation, and bare/barren land. The forested areas have not contributed much in the increase in built up areas.

It is found that sparse vegetation is the major contributor to the dense vegetation, but of low magnitude. The main contributors of net change in dense vegetation are fallow land and bare soil/barren land which is approximately 25 hectares. The rest of the LULC classes exhibited negative results. About 275 hectares of dense forest is converted to sparse category and 75 hectares is encroached by the built-up area. This type of change is recorded in the lower part of the study area particularly in the close vicinity of settlements (Fig. 3). The expansion of settlements and consequently the increase in built up area has exerted pressure on agriculture. It led to a nominal increase in area under agriculture at the cost of clearance of dense forest.

5.4.2. Sparse vegetation

It is notable that about 275 hectares of area of dense forest is converted to sparse class and almost the same area has been gobbled by sprawling settlements. To meet the growing demand of population about 250 hectares of area under sparse vegetation is converted to agriculture. At the same time almost the same area from barren lands is added to sparse class (Figs. 5 and 6).

5.4.3. Built-up area

The built up area increased largely at the cost of sparse vegetation, fallow/open land and barren land. The study area like the other parts of the state experienced a sharp increase in population during the study period. Because of its proximity to Dehradun, the state capital, there is an influx of migrants from the remote areas. These immigrants generally settled at the periphery where there is plenty of open space and free access to the natural resources. It has led to over exploitation of forests for fuel and timber. As a result about 260 hectares of area under sparse vegetation is almost cleared and converted to settlements. To meet the growing demand of the open space, the barren areas are converted into settlement colonies either by the private colonizers or by the local authority. Beside these, all the other classes show insignificant positive or negative contribution (Fig. 6)

5.4.4. Water bodies

Water bodies recorded an increase of about 2.6%. All the classes of land use contributed positively. However, the largest

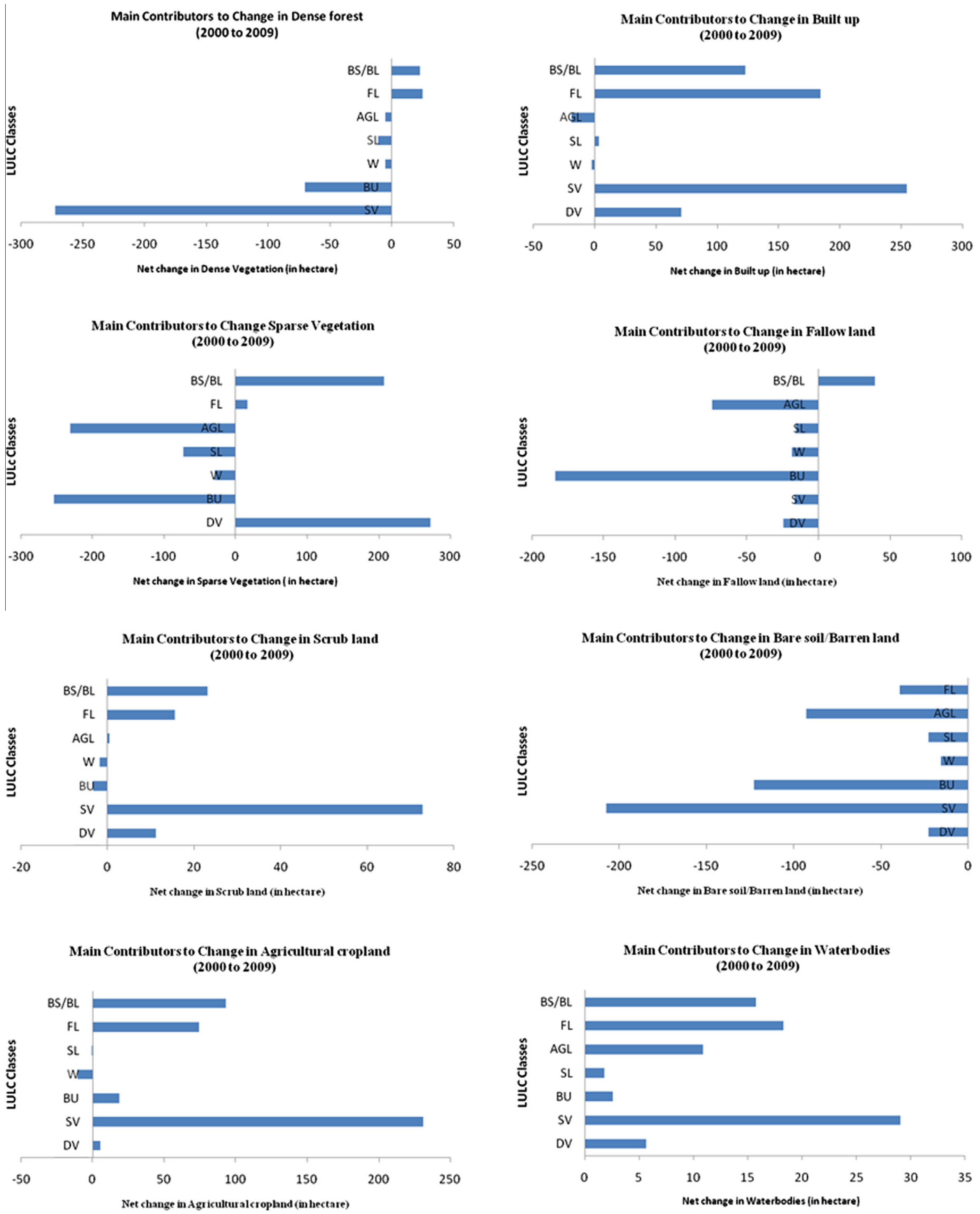

Figure 6 Main contributors to change in each LULC class.

contribution of about 30 hectares is from the sparse vegetation category, followed by fallow land (18 hectare), barren land (16 hectare) and agriculture (11 hectare). The increase in area is the result of efforts of government, NGOs and the stake holders. The check on illegal mining of the river bed has played a key role in conserving the river course and an increase in recharge zone.

5.4.5. Scrub land

The scrub lands recorded an increase of about 2.57%. Dense vegetation, followed by barren class and fallow land has contributed significantly. It is found that during the study period the rainfall was erratic and sporadic in nature. The net effect was that the barren areas which are located in the higher parts of the study area received more rain than others. It provided a

Table 4 Producer and User accuracy- 2000 and 2009.

Land use land cover classes	Producer accuracy (%)		User accuracy (%)	
	2000	2009	2000	2009
Dense vegetation	96.01	88.64	97.60	88.92
Sparse vegetation	78.64	87.66	88.99	89.37
Built-up area	85.80	72.54	81.23	80.78
Water bodies	53.52	86.03	68.47	71.96
Scrub land	69.11	84.52	46.93	89.75
Agricultural cropland	53.12	77.00	61.83	63.90
Fallow land	96.69	68.89	93.98	61.08
Bare soil/barren land	97.48	62.42	89.92	69.92

suitable environment for the germination of scrubs and wild plants. The dense vegetation areas are in the close vicinity of settlements and have been exploited so much that only undergrowths are left. As expected agriculture has played a positive role and built-up area played a negative role in the spatial extent of scrub land (Fig. 6).

5.4.6. Agricultural land

The rising population, expansion of settlements and consequently agricultural development have influenced the land use pattern of the Nun Nadi Watershed. Sparse vegetation, bare soil/barren land and fallow land are the main contributors to change in agricultural area which is ~230, 100 and 80 hectares respectively (Fig. 6).

5.4.7. Fallow land

Fallow land has registered a sharp and significant decline (−43.15%) in area during the study period (Fig. 5). This decline was largely because of a sharp increase in built-up area (180 hectares) which led to an increase in the demand of food and related items. To meet the growing demand of agricultural products because of increasing population the farmers are forced to do intensification of agriculture. Besides, almost all categories of land use except barren lands encroached upon fallow lands in varying degrees.

5.4.8. Bare soil/barren land

Barren lands are ranked three in terms of change rate. It lost about 528.93 hectares of area (60.95%). Sparse vegetation, built-up area and agriculture are largely responsible for the decline in the area of barren lands.

6. Classification accuracy assessment

Evaluation of classification results is an important process in the satellite image classification procedure. In doing so confusion/error matrices were used. It is the most commonly employed approach for evaluating per-pixel classification (Lu and Weng, 2007). The accuracy was assessed with cross-validation against Google Earth Imageries. Using these reference data and the classified maps, confusion matrices were constructed for a two time period. The resulting land use/cover maps of a two time period of 2000 and 2009 had an overall map accuracy of 79.83% and 83.43% (Table 4) respectively. This was reasonably good overall accuracy and accepted for the subsequent analysis and change detection. User's accuracy of individual classes ranged from 61% to 97% and producer's accuracy ranged from 53% to 97%. Kappa statistics/index was computed for each classified map to measure the accuracy of the results.

$$\text{Overall Accuracy} = (3515/4403)79.8319\%(2000) \text{ and } (2896/3471)83.4342\%(2009)$$

$$\text{Kappa Coefficient} = 0.7500(2000) \text{ and } 0.7944(2009)$$

The resulting classification of Landsat land use/cover maps of the year 2000 and 2009 had Kappa statistics of 0.7500 and 0.7944 respectively. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Kappa accounts for all elements of the confusion matrix and excludes the agreement that occurs by chance. Consequently, it provides a more rigorous assessment of classification accuracy.

7. Conclusion

The present study is focused on LULC changes and its rate gives the magnitude and direction in the Nun Nadi Watershed around the Dehradun region within the time periods examined i.e. 2000–2009. Our data clearly show significant changes in the LULC, specially as the area under built-up has increased by 7.12% (approximately 620 hectare). Those people (local or belongs to remote area) who were residing outside for employment and other facilities before 2001 now came back at their native places in Dehradun and nearby villages. The state government has announced many jobs and people got better facilities and services after 2001. As a result, the increasing population pressure led to the encroachment in other land cover for different purposes primarily food; as a result the agriculture land increased to about 400 hectares (3.71%) that shows a positive growth rate. The combined dense and sparse vegetation land shows a negative growth rate in LULC classes. This combined vegetation land recorded approximately 5.50% negative changes from 2000 to 2009. On the other hand, this negative change is attributed to the positive growth of scrub land. The pixel to pixel employed compound interest formula approach in this study shows satisfactory results about land transformation from one class to another and in terms of the accuracy of the LULC classification. Our study provides updated information about the LULC change which is a key factor for environmental degradation i.e. soil erosion (Naqvi et al., 2013), landslides, floods, etc. A thorough evaluation for the identification of such factors would be extremely helpful in devising strategies for sustainable environment management.

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References

Allen, J.C., Barnes, D.F., 1985. The causes of deforestation in developing countries. Ann. Assoc. Am. Geogr. 75, 163–184.

Bauer, M., Yuan, F., Sawaya, K., 2003. Multi-temporal Landsat image classification and change analysis of land cover in the Twin cities (Minnesota) metropolitan area, Second International Workshop on the Analysis of Multi-Temporal Remote Sensing Images. July 16–18, Ispra, Italy, pp. 368–376.

Brockerhoff, M.P., 2000. "BULLETIN", Population.

Civco, D., Hurd, J., Wilson, E., Song, M., Zhang, Y., 2002. A comparison of land use and land cover change detection methods, ASPRS Annual Convention, Washington, DC, p. 12

Dale, V.H., 1997. The relationship between land-use change and climate change. Ecol. Appl. 7, 753–769.

Erle, E., Pontius, R., 2007. Land-use and land-cover change. In: Cutler J. Cleveland (Ed.), Encyclopaedia of Earth, Environmental Information Coalition, National Council for Science and the Environment, Washington, DC. (http://www.eoearth.org/article/Land-use_and_land-cover_change).

IPCC [Intergovernmental Panel on Climate Change], Special report on land use, land-use change, and forestry, Cambridge University Press, Cambridge, UK, 2000.

Jones, B.A., Ritters, K.H., Wickham, J.D., Tankersley, R.D., Jr., O'Neill, R.V., Chaloud, D.J., Smith, E.R., Neale, A.C., 1997. An ecological assessment of the united states mid- atlantic region: a landscape atlas, U.S. Environmental Protection Agency, Report No. EPA/600/R-97/130, U.S. Printing Office, Washington, DC, p. 104.

Lambin, E., Ehrlich, D., 1997. Land-cover changes in sub-Saharan Africa (1982-1991): application of a change index based on remotely sensed surface temperature and vegetation indices at a continental scale. Remote Sens. Environ. 61 (2), 181–200.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., et al, 2001. The causes of land-use and land-cover change: moving beyond the myths. Global Environ. Change 11, 261–269.

Lu, D., Weng, Q., 2007. A survey of image classification methods and techniques for improving classification performance. Int. J. Remote Sens. 28 (5), 823–870.

Macleod, Congation, 1998. A quantitative comparison of change detection algorithms for monitoring eelgrass from remotely sensed data. Photogramm. Eng. Remote Sens. 64 (3), 207–216.

Marzluff, J.M., Ewing, K., 2001. Restoration of fragmented landscapes for the conservation of birds: a general framework and specific recommendations for urbanizing landscapes. Restor. Ecol. 9, 280–292.

Mas, J., 1999. Monitoring land-cover changes: a comparison of change detection techniques. Int. J. Remote Sens. 20 (1), 139–152.

McIver, D.K., Friedl, M.A., 2002. Using prior probabilities in decision-tree classification of remotely sensed data. Remote Sens. Environ. 81, 253–261.

Melillo, J.M., McGuire, A.D., Kickkighter, D.W., Moore, B., Vorosmarty, C.J., chloss, A.L., 1993. Global climate change and terrestrial net primary production. Nature 363, 234–240.

Myneni, R.B., Keeling, C.D., Tucker, C.J., Asrar, G., Nemani, R.R., 1997. Increased plant growth in the northern high latitudes from 1981 to 1991. Nature 386, 698–702.

Naqvi, H.R., Mallick, J., Devi, L.M., Siddiqui, M.A., 2013. Multitemporal annual soil loss risk mapping employing revised universal soil loss estimation (RUSLE) model in Nun Nadi Watershed, Uttrakhand (India). Arab. J. Geosci. 6, 4045–4056. http://dx.doi.org/10.1007/s12517-012-0661-z.

Puyravaud, J., 2003. Standardizing the calculation of the annual rate of deforestation. For. Ecol. Manage. 177, 593–596.

Singh, A., 1989. Review article digital change detection techniques using remotely-sensed data. Int. J. Remote Sens. 10 (6), 989–1003.

Stow, D., 1990. Land use change detection based on multi-date imagery from different satellite sensor systems. Geocarto Int. 5 (3), 3–12.

Vitousek, P.M., 1992. Global environmental change: an introduction. Annu. Rev. Ecol. Syst. 23, 1–14.

Vitousek, P.M., 1994. Beyond global warming: ecology and global change. Ecology 75, 1861–1876.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of Earth's ecosystems. Science 277, 494–499.

Weismiller, R.A., Kristof, S.Y., Scholz, D.K., Anuta, P.E., Momin, S.A., 1977. Change detection in coastal zone environments. Photogramm Eng. Remote Sens. 43, 1533–1539.

Woodwell, G.H., Hobbie, J.E., Houghton, R.A., Mellio, J.H., Peterson, B.J., Shaver, G.R., Stone, T.A., Moore, B., Park, A.B., 1983. Deforestation measured by landsat: steps toward a method DOE/EV 10468 NTTS, Spring field, VA, p. 62.

Wu, W., Shao, G., 2002. Optimal combinations of data, classifiers, remote sensing. Can. J. Remote Sens. 28 (4), 601–609.

Yuan, F., Sawaya, K., Loeffelholz, B., Bauer, M., 2005. Land cover classification and change analysis of the twin cities (Minnesota) metropolitan area by multi-temporal landsat remote sensing of environment. Remote Sens. Environ. 98, 317–328.

Zhu, A.X., 1997. Measuring uncertainty in class assignment for natural resource maps under fuzzy logic. Photogramm. Eng. Remote Sens. 63 (10), 1195–1202.